A Component Model of Spatial Locality

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Memory Wall and Locality

- Memory wall
- Locality
  - temporal locality: enable cache reuse
  - spatial locality: implicit data prefetching and better cache utilization

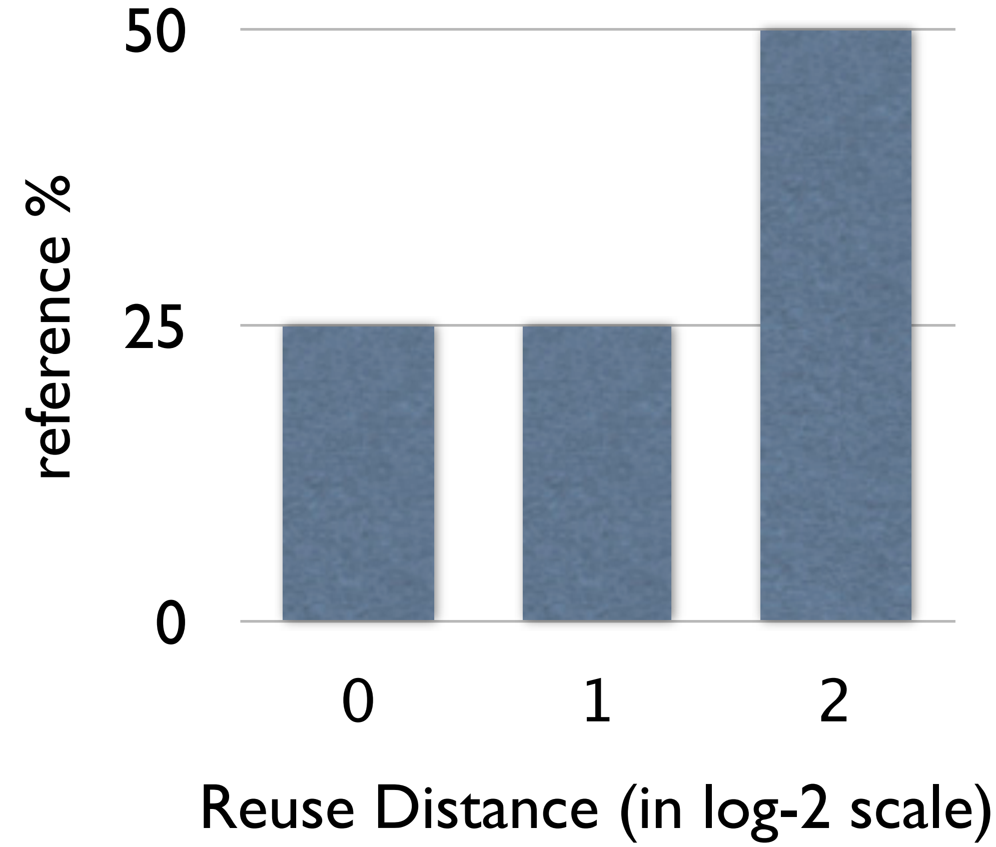
Spatial Locality

- Three types
  - intra-block spatial locality ★
  - inter-block spatial locality
  - adjacent-block spatial locality ★

Reuse Distance

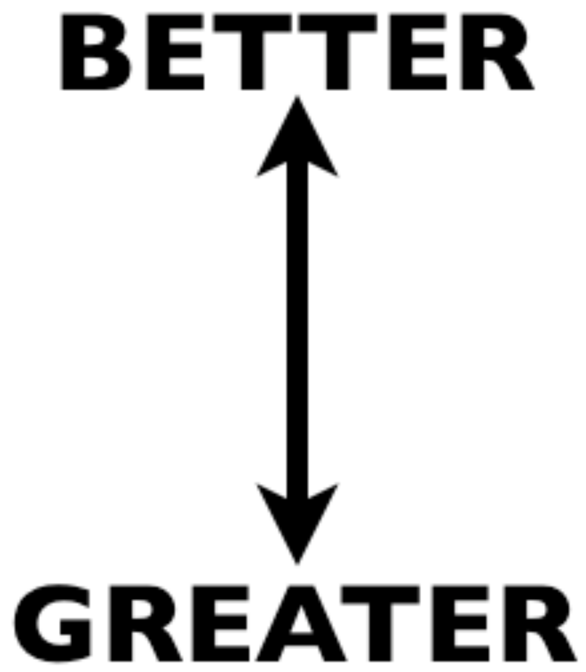
- Reuse distance
  - the volume of data referenced between this and the previous access
- Reuse signature
  - the distribution of all finite reuse distances

access trace	A	B	C	A	A	C	B
rd	∞	∞	∞	2	0	1	2



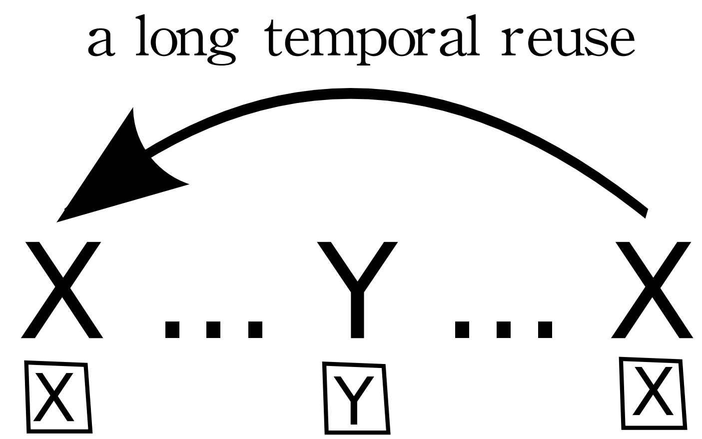
Basic Idea

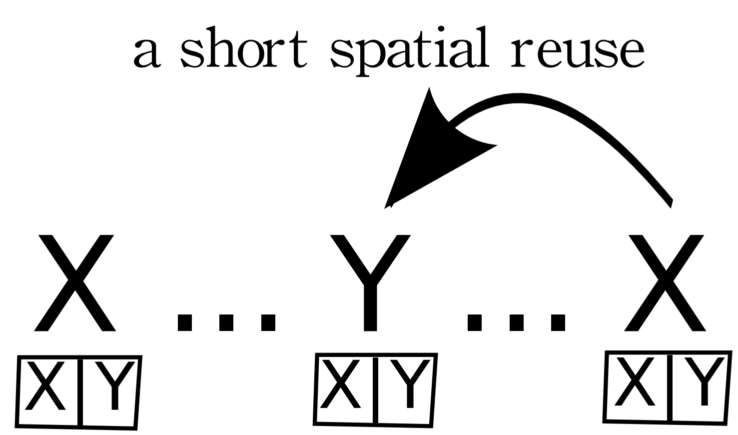
- Spatial locality
- Reduction on reuse distances when measuring block size doubled



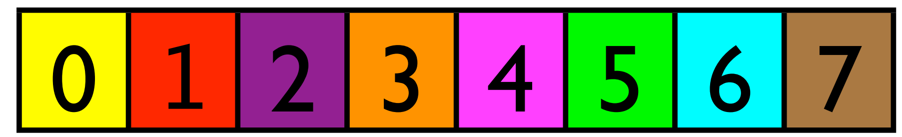
Reduction in Reuse Distance

- Two cases of reductions
  - no intercept: reduced by half at most
  - intercept: may reduce it to constant

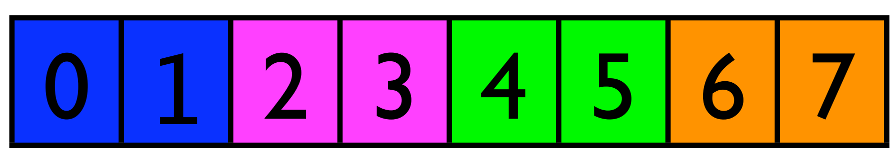




Contiguous Access

- An array with 8 elements 

  - access 0, 1, 2, 3, 4, 5, 6, 7 repeatedly
- Rd measured with single-element block
  - all are 7
- Rd measured with 2-element block



  - half reduced to 0 (constant)
  - half reduced to 3 (dependent on array size)

Measuring Spatial Reuse

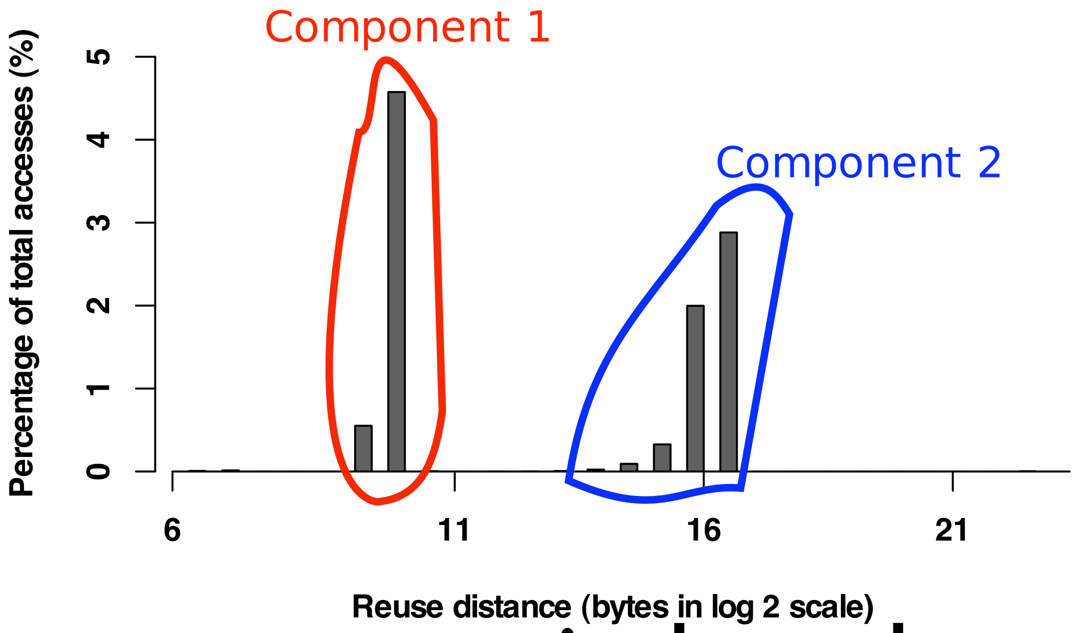
- Measure the change of every reuse distance
  - running two reuse distance analyzers simultaneously
- Criteria for effective spatial reuse
  - machine independent (reducing factor $\geq$8)
  - machine dependent (L1&L2 cache sizes)

Quantitative Scoring

- Spatial-locality quality score (SLQ)
  - portion of effective spatial reuse for each range of reuse distances, normalized to the best case (contiguous access)
    - 0 means no spatial locality and 1 means best spatial locality

Locality Components

- Program level
  - functions or loops
- Behavior level
  - adjacent reuse distance ranges in length, which forms a peak
    - similar in temporal locality but maybe very different in spatial locality



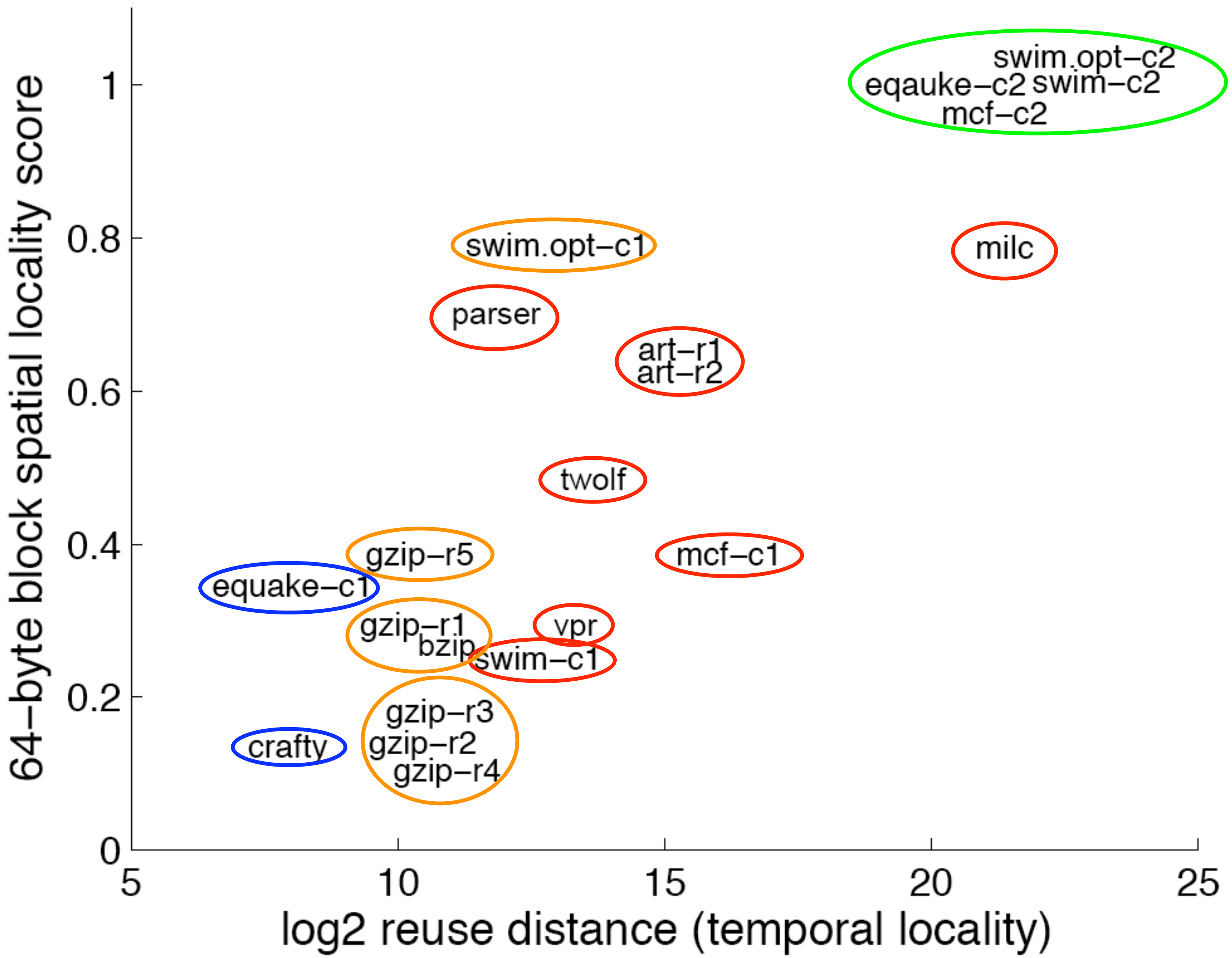
Locality Components

- Three metrics
  - total size
  - temporal locality: average reuse distance
  - spatial locality: average SLQ
- More findings than a single global result

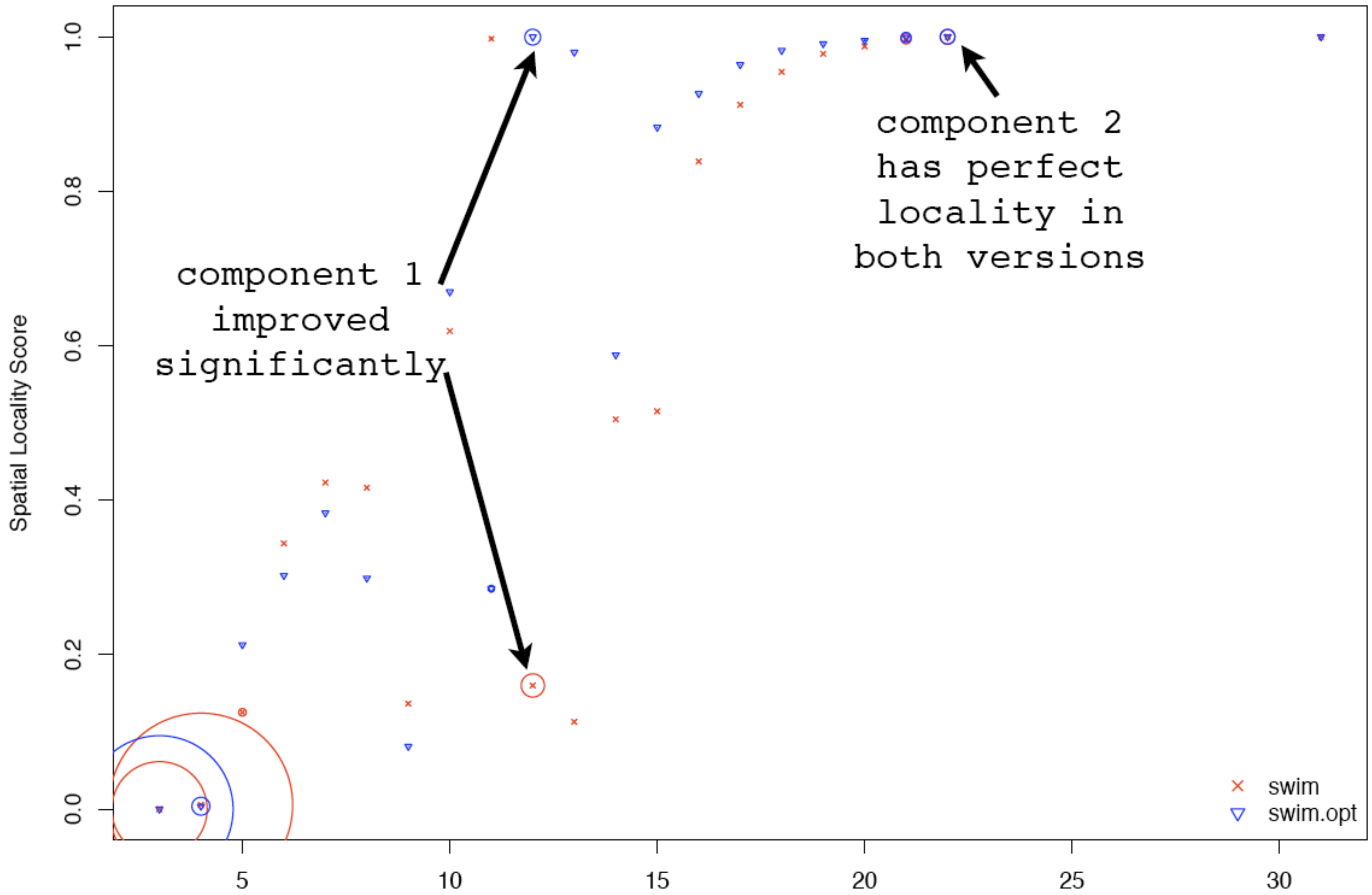
Locality Profiling Tools

- Full trace analysis
  - dynamic binary instrumentation based on Valgrind
  - static source instrumentation based on GCC
- Sampling analysis
  - reservoir sampling (based on SLO [Beyls & D'Hollander])

All Benchmark Results



Result for Array Regrouping on Swim

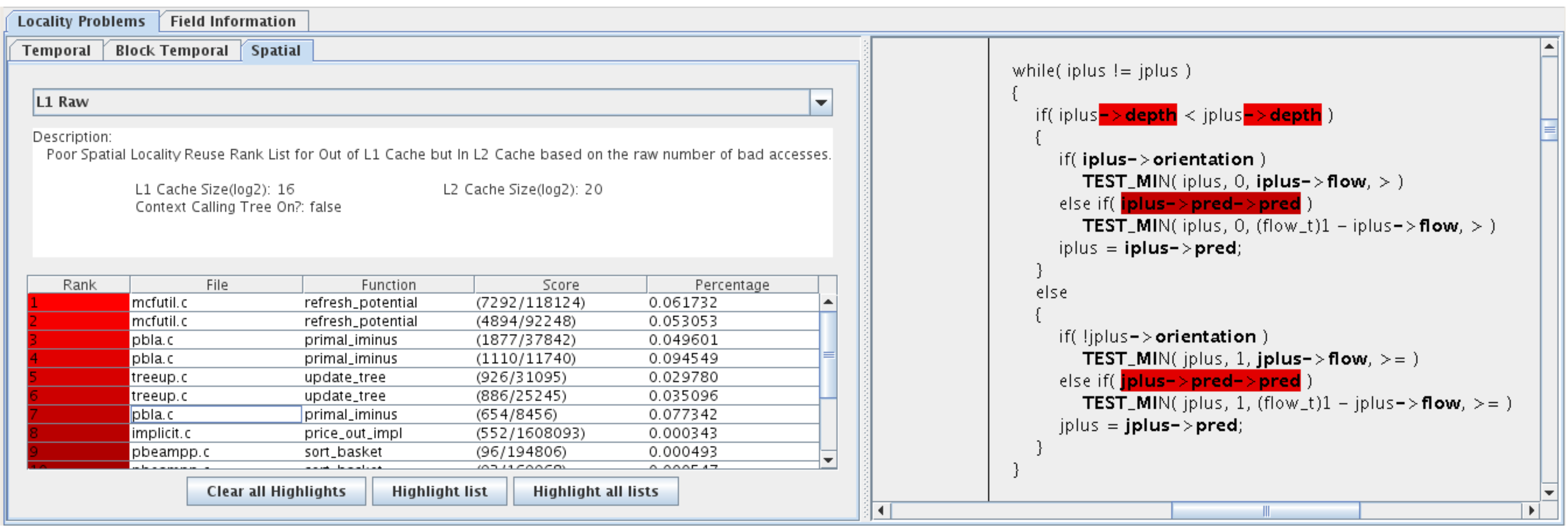


A User Study

- Locality tuning for a 2200-line machine translation application
  - using GCC-based tool with calling context tree
  - worst spatial locality occurs in a 10-line library function
  - 7% improvement after 6-line change
  - acceptable loss of precision in the translation

Spatial Locality Ranking

- A sampling-based tool extended from SLO
- Worst spatial locality problems identified for mcf



Summary

- A new model for spatial locality
  - based on reuse distance
  - models intra-block and adjacent-block spatial locality both
  - component-based, on both behavior and program levels
  - promising as part of performance tools

Q & A